

**Report to CTCDC on Minimum Yellow Light Change Interval
Timing for Signalized Intersections**

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Background

In 2013, the California Traffic Control Devices Committee (CTCDC) convened a Subcommittee of 19 members, chaired by Hamid Bahadori, inclusive of a broad spectrum of stakeholders and traffic experts to review the protocols for determining the minimum yellow light change interval timing for signalized intersections in California. The subcommittee issued a series of recommendations for changes to the **Standards** and Guidance Statements for the minimum yellow light change interval for the through movement. These recommendations were adopted by Caltrans and incorporated into the 2014 revision of the California MUTCD. Jurisdictions were mandated to comply with the new protocols by August 1, 2015 for intersections enforced with automated enforcement systems (red light cameras) and by August 1, 2017 for all other intersections throughout California.

Due to lack of time and a need for further study, the subcommittee did not offer recommendations for changes to the **Standards** for the minimum yellow light change interval for exclusive turn movements and agreed to defer that discussion to a later date. As a result, the CAMUTCD does not contain a **Standard** for determining the minimum yellow light change interval for exclusive turn movements.

This report reviews the violation and citation data from numerous red light camera locations throughout California where the yellow interval was adjusted in response to the newly mandated protocols. Also included in this report is a brief discussion of an updated theory for accurately determining the minimum yellow light change interval for turning lanes presented at the 2016 ITE International Convention.

Part 1 – Results of New Signal Timing Protocols.

Changes to California's Minimum Yellow Interval Timing Protocols in 2014 CAMUTCD

Previous Yellow Interval Timing Rules	New Yellow Interval Timing Rules
<p>Standard: Permitted to use posted speed limit or prima facie speed limit in calculating the minimum yellow interval. No requirement to set yellow time based on actual speed of traffic on roadway.</p>	<p>Standard: Shall use 85th percentile speed of free-flow traffic rounded up to next highest 5 mph increment</p> <p align="center">or</p> <p>If no speed survey has been done for that section of roadway, add 7 mph to posted speed limit for posted speeds 30 mph and above and add 10 mph to posted speed limit for posted speeds 25 mph and below.</p>
<p>No requirement to consider grade of roadway in setting yellow interval.</p>	<p>New Guidance Statement added that practitioners should consider grade of roadway when setting yellow interval.</p>

No requirement to consider perception-reaction time of drivers beyond the 1.0 second PRT most often used in calculating the yellow interval.	New Guidance statement added that practitioners should consider perception-reaction time of drivers which may exceed 1.0 second.
Specific permission to use 3 second minimum yellow interval for any protected right or left-turn movement. Optional for practitioners to consider longer yellow intervals for protected left-turn and right-turn movements.	Specific reference to permission for use of 3 second minimum yellow interval for protected right or left-turn movements deleted. New Guidance statement added that practitioners should consider longer yellow intervals for protected left-turn and right-turn movements, especially where the exclusive turn lane exceeds 150 feet in length.

Methodology

Violation and Citation data was collected from jurisdictions using automated enforcement, aka Red Light Cameras, where changes were made in the length of the yellow interval timing in response to the new protocols. Where available, the before and after interval lengths were noted.

A before and after analysis of violation and citation rates was performed, and a percent change in those rates was calculated.

Limitations

The type and specificity of violation and citation data varied by jurisdiction due to cities contracting with differing vendors, quality of record keeping, and willingness to provide data. A number of jurisdictions disbanded their programs around the time the new protocols went into effect, preventing sufficient data collection to perform an analysis. In some cases, only violation or citation data was available. For most jurisdictions, monthly data was available for each intersection approach monitored by Red Light Cameras. However, this presented a problem as the data for both through lanes and turning lanes is often combined into one total for the intersection approach. Since the new timing protocols only mandated a change to the Standard for through lanes, data from lanes where the timing was changed was mixed with data from lanes where the timing remained the same. Where available, data from each lane separately was analyzed, but this was not always possible. Therefore, where data in both through and turning lanes was mixed, the reduction in the overall violation or citation rate may have been greater than calculated.

The individual results from each studied jurisdiction follows.

West Hollywood, CA

The City of West Hollywood, CA implemented a red light photo enforcement program in 1999. Twenty four approaches at a total of 8 intersections were monitored by red light cameras. Of those, 16 approaches were monitored on a continuous basis. Uninterrupted monthly citation figures, therefore, only exist for the 16 approaches where the enforcement cameras were continuously functional. The West Hollywood program was unique in that the city's automated enforcement program only targeted violations occurring in straight through lanes. Therefore, no turning lane violations were mixed into

the data, providing the opportunity for an evaluation of purely straight through violations. In September 2015, the city suspended their program to change camera vendors. The program came back online only recently with changes in the operation of the program and upgrades to the camera equipment. Therefore, for consistency, this analysis only covers the period of the original program through September 2015.

For most of the program’s history, traffic signal yellow intervals in West Hollywood had been set at the absolute minimum time based on the posted speed limit of the roadway. In 2012, the city began implementing a new policy of setting the yellow interval based on the posted speed limit plus an additional 5 mph. This resulted in 0.3 s of additional time being added to the yellow interval at intersections where the new timing protocol had been employed. The process of re-timing the signals throughout the city was not fully completed and some red light camera enforced intersections were not upgraded to the new timing protocols.

In early 2015, in anticipation of compliance with the new MUTCD protocols, the city increased the yellow interval at all their red light camera intersection approaches based on the posted speed + 7 mph.

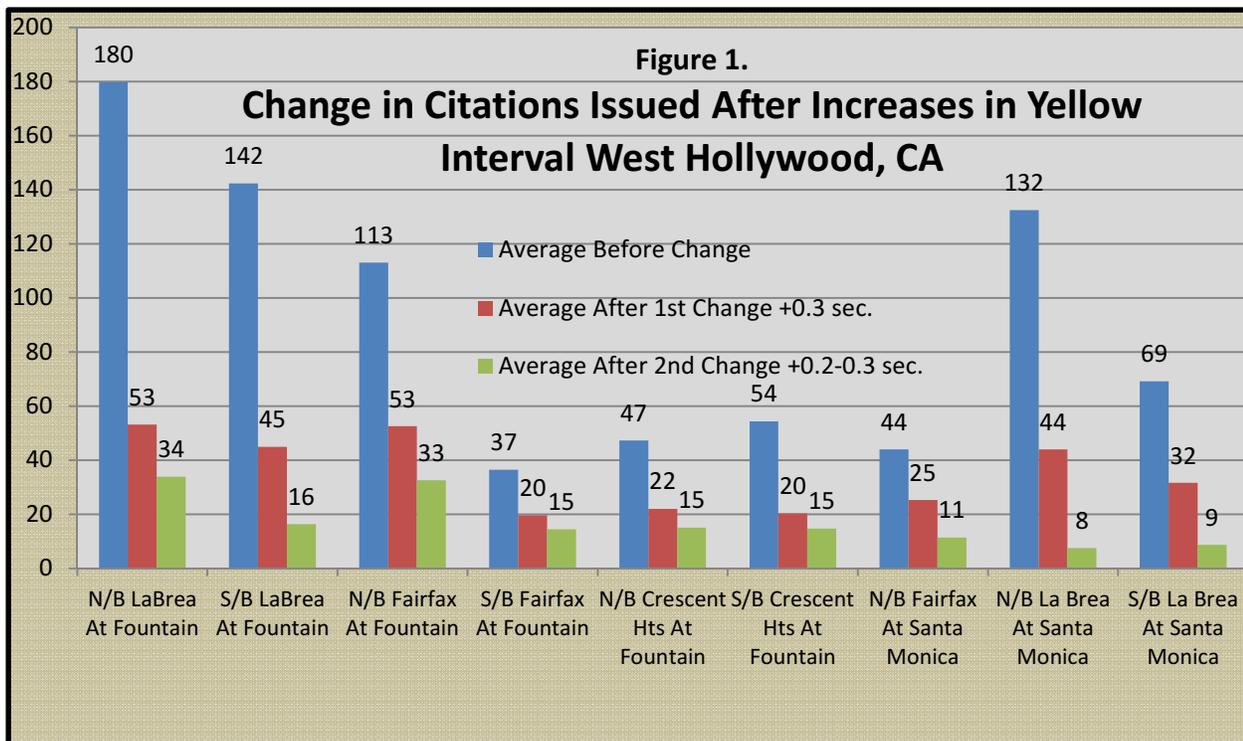
Results

Table 1 shows the change in citations after each increase in the yellow interval. 1st Updated Yellow reflects the yellow interval increase that occurred in 2012 – 2013 due to the addition of 5 mph to the posted speed limit. 2nd Updated Yellow reflects the yellow interval increase that occurred in early 2015 due to the new MUTCD timing protocols using the posted speed limit + 7 mph.

Location	Original Yellow	1 st Updated Yellow	2 nd Updated Yellow	Average Before Change	Average After Change	% Change	Average After 2 nd Change	% Change	Overall % Change
N/B LaBrea At Fountain	3.6	3.9	4.1	180	53	-70.4%	34	-36.2%	-81.16%
S/B LaBrea At Fountain	3.6	3.9	4.1	142	45	-68.4%	16	-63.7%	-88.52%
N/B Fairfax At Fountain	3.6	3.9	4.1	113	53	-53.5%	33	-37.9%	-71.15%
S/B Fairfax At Fountain	3.6	3.9	4.1	37	20	-46.3%	15	-26.0%	-60.27%
N/B Crescent Hts At Fountain	3.6	3.9	4.1	47	22	-53.5%	15	-31.3%	-68.05%
S/B Crescent Hts At Fountain	3.6	3.9	4.1	54	20	-62.4%	15	-27.7%	-72.85%
N/B Fairfax At Santa Monica	3.6	3.9	4.2	44	25	-42.6%	11	-54.7%	-73.99%
N/B La Brea At Santa Monica	3.6	3.9	4.2	132	44	-66.8%	8	-82.8%	-94.28%
S/B La Brea At Santa Monica	3.6	3.9	4.2	69	32	-54.3%	9	-72.4%	-87.40%
Totals				819	313	-61.7%	155	-50.6%	-81.1%

By increasing the yellow interval by 0.3 sec., traffic engineers were able to achieve an overall 62% reduction in red light running at the locations analyzed in this study. A further 51% decrease in red light running was achieved when the yellow interval was increased another 0.2 – 0.3 sec. in response to the new MUTCD timing protocols. Overall, the city achieved an 81% reduction in red light running at their photo enforced intersections as a result of increasing the yellow interval. Some intersections saw as much as a 94% decrease in red light running, resulting in a violation less than once every three days.

Figure 1 shows the results in graphical format.



The increase in the yellow interval due to adding 5 mph to the posted speed limit reduced red light running significantly. An additional significant improvement in safety was achieved by further increasing the yellow interval based on the 85th percentile speed.

Beverly Hills, CA

The City of Beverly Hills, CA implemented a red light photo enforcement program in the late 1990's. In 2008, the city switched to a new vendor. Nine approaches at a total of 6 intersections were monitored by red light cameras. In September 2014, the city suspended their program to again change camera vendors. The program came back online in June 2015, at about the time the new yellow timing protocols went into effect.

For most of the program's history, yellow intervals in Beverly Hills had been set within about 0.1 second of the absolute minimum time based on the posted speed limit of the roadway. When the program resumed in June 2015, the city increased the yellow interval in the through lanes at all red light camera enforced intersections, often exceeding the required minimums based on the 85th percentile speed by about 0.3 sec. However, it should be noted that the city does not consider grade when setting the yellow interval. Additionally, speed surveys conducted in Beverly Hills tend to find lower 85th percentile speeds than similar roadways in other jurisdictions. Therefore, what appears to be additional yellow time at Beverly Hills red light camera intersections may not represent timing above what is actually required by motorists approaching those intersections.

At three red light camera intersections the city has set the yellow interval for the dedicated left turn lanes at 4.2 seconds. At two other intersections, the city has set the yellow interval for dedicated left turn lanes at 3.2 seconds even though the length of the turn pocket at one approach is over 230 feet.

Results

For this analysis, at each intersection monitored by red light cameras under both the prior and current programs, we compared the total monthly citations for the last full month of the prior program, August 2014, with the average number of monthly citations for the period February 2016 through June 2017. We also compared the number of citations in August 2014 to the number of citations in July 2017. These calculations allowed us to directly compare the number of ticketed violations under both the old and new signal timing protocols. The ticketing data includes citations issued in through lanes as well as dedicated turning lanes (where enforced).

Table 2 shows the change in citations after the increase in the yellow interval. Original Yellow reflects the yellow interval that existed during the prior program based on the posted speed limit. These yellow times are estimated based on city staff’s explanation of how the yellow time had been set. Updated Yellow reflects the yellow interval increase that occurred when the new program went into effect using the 85th percentile speed of traffic.

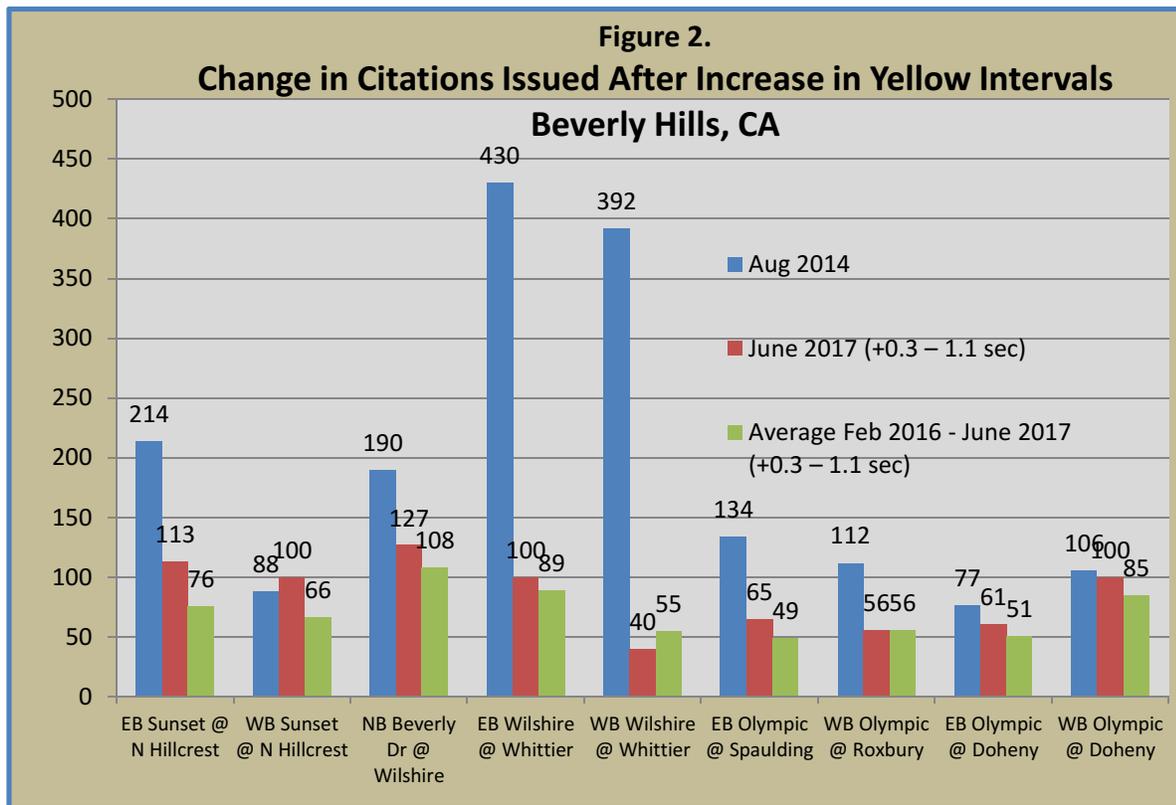
	Location	Original Yellow (est)	Updated Yellow	Aug 2014	June 2017	Average Feb 2016 - June 2017	% Change Aug 2014 vs June 2017	% Change Aug 2014 vs Ave Feb 2016 – June 2017
Comparison to Prior Program	EB Sunset @ N Hillcrest	3.7	4.2	214	113	76	-47.20%	-64.67%
	WB Sunset @ N Hillcrest	3.7	4.2	88	100	66	13.64%	-24.55%
	NB Beverly Dr @ Wilshire	3.1	4.2	190	127	108	-33.16%	-42.95%
	EB Wilshire @ Whittier	3.3	4.2	430	100	89	-76.74%	-79.30%
	WB Wilshire @ Whittier	3.3	4.2	392	40	55	-89.80%	-85.99%
	EB Olympic @ Spaulding	3.7	4.2	134	65	49	-51.49%	-63.23%
	WB Olympic @ Roxbury	3.7	4.2	112	56	56	-50.00%	-50.30%
	EB Olympic @ Doheny	3.7	4.2	77	61	51	-20.78%	-33.77%
	WB Olympic @ Doheny	3.7	4.2	106	100	85	-5.66%	-19.81%
	Total Prior Locations Only			1743	762	635	-56.28%	-63.55%

By increasing the yellow interval by 0.3 – 1.1 sec., the City of Beverly Hills was able to achieve an overall 64% reduction in red light running at the locations analyzed in this study. Some intersections saw as much as a 90% decrease in red light running.

Note that although the yellow interval was increased by about 1.1 sec. at NB Beverly Dr. @ Wilshire, the number of citations dropped by only about 43%. This is due to the fact that a majority of the citations issued at this location are for “rolling-right-turns” on red which are generally unaffected by changes in the yellow interval. Violations in the through lanes likely dropped significantly more, but we were unable to verify this as the city’s vendor does not currently provide a report of the number of violations occurring in each lane separately.

Additionally, the location that had the greatest decrease in red light running, Wilshire @ Whittier, was the location where we had previously noted that the posted speed limit was almost 10 mph lower than the 85th percentile speed.

Figure 2 presents the results in graphical format.



Although the city has achieved a significant improvement in safety by increasing the yellow interval, a number of locations continue to experience relatively large numbers of red light running incidents. This suggests that the current yellow intervals are still sub-optimal at some intersection approaches and the city should consider adding additional yellow warning time to some signal phases.

Commerce, CA

The city of Commerce initiated automated enforcement in November 2007. Nine intersection approaches in the city are monitored with red light cameras. The junction of Atlantic Blvd, Eastern Ave., Telegraph Rd., Ferguson Dr., Triggs St., and the Santa Ana Freeway ramp, aka “the mixmaster”, one of the most confusing intersections in Southern California, is located in Commerce. Three intersection approaches are monitored by red light camera systems at this location.

The previous timing of the yellow interval appears to have ranged between 4.0 and 5.0 seconds. The basis for the prior timing at each location is unclear. In late 2015, the city increased the yellow interval by 0.5 sec. at five red light camera approaches. Again, it is unclear how the city determined which locations would be increased and by what amount.

For this analysis, we compared the violations recorded in each lane before and after the signal timing was increased. For one location, Slauson Ave. at Gage Ave., where the yellow interval had previously

been set to 4.5 sec., very few violations had been occurring in the through lanes prior to the change and no further reductions were possible. We eliminated this intersection from the analysis.

Access to reports listing violations by lane were limited to July – Dec. 2014, Sept. 2015, Sept. 2016, and Jan. 2017. The yellow interval was increased by 0.5 sec. on November 12, 2015 at the intersections of southbound Atlantic Blvd. at Telegraph Rd. and westbound Telegraph Rd. at Atlantic Blvd. For these intersections, we compared the number of violations in September 2015 with an average of the number of violations occurring in September 2016 and January 2017.

At the intersection of eastbound Slauson Ave. and Eastern Ave., the yellow interval was increased by 0.5 sec. on September 2, 2015. For this intersection, we compared the average of the number of violations occurring in July through December 2014 with the average of the number of violations occurring in September 2015, September 2016, and January 2017.

Results

Table 3 shows the change in violations after the increase in the yellow interval.

Table 3. Change in Violations After Increase in Yellow Intervals - Commerce, CA						
Location	Original Yellow	Updated Yellow	# of Violations Prior to Change	# of Violations After Change	% Change	Change Date
Atlantic SB at Telegraph (3 Through Lanes)	4.0	4.5	544	298	-45.22%	11/12/2015
Telegraph WB at Atlantic (2 Through Lanes)	4.5	5.0	181	105	-41.99%	11/12/2015
Telegraph WB at Atlantic (LT Lane)	4.5	5.0	51	23	-54.90%	11/12/2015
Slauson EB at Eastern (2 Through Lanes)	4.5	5.0	57	29	-49.12%	9/2/2015

The city achieved a reduction in red light running violations ranging from 42% to 55% at the intersections where the yellow interval was increased by 0.5 seconds in response to the new signal timing protocols. This includes the 55% reduction in the left turn lane at westbound Telegraph Rd. at Atlantic Blvd. Note that this increase occurred due to the fact that movements in the left turn lane are controlled by the same signal as the through lanes.

Some locations, including the intersection of southbound Atlantic Blvd. at Telegraph Rd. within the mixmaster, continue to experience a relatively high volume of red light violations. This is possibly due to the confusing nature of the intersection which might require longer reaction times from drivers. Further increasing the yellow interval at this location and others in Commerce could likely reduce or eliminate these violations and improve safety.

Culver City, CA

Culver City has employed red light cameras since at least early 2000. The city issues the most red light camera tickets of any city in California. As of data received through September 2017, the city was on track to issue approximately 47,000 tickets in 2017.

The city upgraded their yellow signal timing in June 2015 in anticipation of the new timing protocols. The city appears to be using the posted speed limit plus 7 mph method of calculating the yellow interval. However, this likely still puts the city in compliance with the minimum required standard.

Analysis of the change in red light violations was complicated by the fact that around the same time of the signal timing changes, the city upgraded the camera system, added lanes of enforcement (primarily to ticket right turn violations), moved some camera locations, and lowered the activation speed threshold from 15 mph to 10 mph. Many of these changes were completed over numerous months, making it virtually impossible to track and adjust for the changes.

Further, due to the extremely high number of red light camera locations, city staff was unable to provide lane-by-lane violation reports for all locations. We therefore asked and received the lane-by-lane violation reports for the two months before and two months after the yellow interval timing was increased at about half of the photo enforced intersections.

Results

Table 4 shows the change in violations after the increase in the yellow interval. The analysis is for the through movement lanes except where indicated.

Table 4. Change in Violations After Increase in Yellow Intervals - Culver City, CA					
Location	Prior Yellow	Updated Yellow	# of Violations Apr & May 2015	# of Violations July & Aug 2015	% Change
N/B LA CIENEGA BLVD/WASHINGTON BL	3.9	4.3	288	181	-37%
S/B SEPULVEDA/GREEN VALLEY CIR	3.9	4.3	402	244	-39%
N/B SEPULVEDA/GREEN VALLEY CIR	3.9	4.3	338	228	-33%
W/B SLAUSON/BUCKINGHAM	4.3	5.1	296	154	-48%
E/B SLAUSON/BUCKINGHAM	4.3	5.1	251	66	-74%
W/B WASHINGTON BL/BEETHOVEN	3.9	4.3	195	114	-42%
W/B WASHINGTON BL/BEETHOVEN LT	3.9	4.3	153	127	-17%
E/B WASHINGTON BL/BEETHOVEN	3.9	4.3	196	90	-54%
W/B WASHINGTON BL/BEETHOVEN LT	3.9	4.3	278	151	-46%
E/B WASHINGTON BLVD/HELMS	3.9	4.3	226	112	-50%
W/B WASHINGTON BLVD/HELMS	3.9	4.3	285	182	-36%
E/B WASHINGTON BL/SAWTELLE	3.9	4.3	321	211	-34%
(S)W/B JEFFERSON/COTA	3.9	4.3	334	76	-77%
Total			3563	1936	-46%

The city achieved a reduction in red light running violations ranging from 33% to 77% in the through lanes where the yellow interval was increased by 0.4 seconds in response to the new signal timing protocols. A 48% to 74% reduction in red light running violations was achieved at the intersection where the yellow interval was increased by 0.8 seconds. Overall, the city experienced a 46% decrease in violations at the intersections studied.

Although Culver City reduced red light running violations by about 50% by increasing the yellow interval in accordance with the new signal timing protocols, due to other changes made by the city in their red light camera program, the city is now issuing more tickets than before the signal timing changes were made.

Further increasing the yellow intervals in Culver City where violations remain high would likely improve safety in the city. Additionally, enacting standards for the proper minimum yellow interval in dedicated turning lanes would also serve to reduce violations in those lanes.

Menlo Park, CA

Menlo Park enforces five approaches at four intersections with red light cameras. All intersections are on state highways and the signal timing is controlled by Caltrans. The two photo enforced intersections on Bayfront Expressway are inapplicable to this study. The cameras at Bayfront and Willow only capture left turn violations and the signal timing for the two long dedicated left turn lanes remains unchanged at 3.6 seconds. The cameras at Bayfront and Chilco began operating in January 2017 and it is assumed the signal timing was set properly according to the new protocols from inception.

According to Caltrans staff, signal timing was upgraded to the new standards on November 20, 2015 at El Camino @ Ravenswood and on December 11, 2015 at El Camino @ Glenwood. At both intersections, the yellow intervals for the through movements were increased from 3.7 seconds to 4.1 seconds and the yellow interval for the left turn movements were increased from 3.0 seconds to 4.1 seconds.

City staff was unable to provide lane-by-lane reports for the months immediately before and after the signal timing changes. However, we obtained the lane-by-lane reports for August 2015 and March 2016 from the website HighwayRobbery.net, and used these two months' data for our analysis.

Results

Table 5 shows the change in violations after the increase in the yellow interval.

Table 5. Change in Violations After Increase in Yellow Intervals - Menlo Pqrk, CA						
Location	Movements	Prior Yellow	Updated Yellow	# of Violations Aug 2015	# of Violations Mar 2016	% Change
El Camino SB @ Ravenswood	Lane 1 LT	3.0	4.1	42	23	-45%
	Lanes 2&3 TH	3.7	4.1	120	42	-65%
	Lane 4 RT	3.7	4.1	48	23	-52%
El Camino NB @ Ravenswood	Lane 1 LT	3.0	4.1	13	6	-54%
	Lanes 2&3 TH	3.7	4.1	69	35	-49%
	Lane 4 RT	3.7	4.1	318	466	47%
El Camino NB @ Glenwood	Lane 1 LT	3.0	4.1	outage	11	outage
	Lanes 2&3 TH	3.7	4.1	127	75	-41%
	Lane 4 RT	3.7	4.1	85	66	-22%
Totals	All Left Turn	3.0	4.1	55	29	-47%
	All Through	3.7	4.1	316	152	-52%

The city achieved a reduction in red light running violations ranging from 41% to 65% in the through lanes where Caltrans increased the yellow interval by 0.4 seconds in response to the new signal timing protocols. A 45% to 54% reduction in red light running violations was achieved in dedicated left turn lanes where the yellow interval was increased by 1.1 seconds. Overall, the city experienced a 52% reduction in violations in through lanes and a 47% reduction in left turn lanes.

Further reductions in red light running are likely possible in Menlo Park by increasing the yellow interval to about 4.5 seconds in the through lanes. Caltrans should also consider increasing the yellow intervals for the two long dedicated left turn lanes at Bayfront Expy and Willow Rd. and the one long dedicated left turn lane at Bayfront Expy and Chilco St.

Fremont, CA

The City of Fremont enforces 10 intersection approaches in the city using red light cameras. Two enforced intersections are on Mission Blvd., a state highway. Caltrans controls the signal timing at these two locations and had previously increased the yellow intervals in 2010 and 2012. We were not able to ascertain whether any additional increases were necessary or made at either of these intersections in response to the new signal timing protocols.

In early 2015, Fremont commissioned new speed surveys throughout the city to comply with vehicle code requirements for using radar for speed enforcement. In August 2015, city engineers increased the yellow interval at two locations, Mowry Ave. at Blacow Rd. and Mowry Ave at Farwell Dr. using the updated speed surveys to comply with the new signal timing protocols. At both locations the yellow interval for the dedicated left turn lane was increased from 3.5 sec. to 4.7 sec. and the yellow interval for the through lanes was increased from 4.0 sec. to 4.7 sec. As a result, red light running violations and citations plummeted by up to 77%.

According to city staff and news reports, the city was not happy with the new speed surveys conducted in early 2015 as the measured 85th percentile speeds required an increase in the speed limit of 5 mph on a few roadways, including Mowry Ave. Subsequently, the city requested that their consultant re-do the surveys on twelve street segments. In every instance, the consultant found 85th percentile speeds on these roadways significantly lower than they had measured earlier in the year, obviating the need to increase any speed limits in the city.

In February 2016, the city used the new speed survey for Mowry Ave., which had previously been found to have an 85th percentile speed of 47.5 mph and which had now been measured at 39 mph in the new survey, to justify lowering the yellow interval in the through lanes back down to 4.0 sec. and to 3.9 seconds in the left lanes. As a result, red light running violations and citations skyrocketed by up to 915%.

After a public outcry and news media investigation, in November 2016 the city again increased the yellow interval in the through lanes to 4.7 sec. but left the yellow interval in the left turn lanes at 3.9 sec. Red light running violations and citations again decreased to levels slightly above levels experienced during the previous period of increase. The slightly elevated violations and citations in this period compared to the previous period is likely due to additional violations occurring in the left turn lanes as a result of leaving the left turn yellow intervals at 3.9 sec. rather than returning them to the higher 4.7 sec. duration of the first period of increase.

In August 2017, city engineers again reduced the yellow interval in the through lanes to 4.5 sec. and increased the yellow interval in the left turn lanes to 4.0 sec. As a result, red light running violations and citations increased once again.

Results

Table 6 shows the changes in violations after the increases and decreases in the yellow interval. Note that lane-by-lane reports were not available for this analysis so the numbers represent violations occurring in all lanes for all movements aggregated together.

Table 6. Changes in Violations and Citations After Changes in Yellow Intervals - Fremont, CA						
	Yellow Interval Left	Yellow Interval Through	Nbd Mowry at Blacow		Sbd Mowry at Farwell	
			Violations	Citations	Violations	Citations
Ave. Aug 2014 - Jul 2015	3.5	4.0	90	57	344	242
Ave. Aug 2015 - Jan 2016	4.7	4.7	50	18	88	55
% Change			-44%	-69%	-74%	-77%
Ave. Feb 2016 - Oct 2016	3.9	4.0	306	178	389	281
% Change			511%	915%	342%	413%
Ave. Nov 2016 - Jul 2017	3.9	4.7	67	31	110	73
% Change			-78%	-83%	-72%	-74%
Ave. Aug 2017 - Oct 2017	4.0	4.5	115	36	181	74
% Change			71%	17%	65%	2%
Overall % Change			28%	-37%	-47%	-69%

Although the city did eventually increase the yellow interval, the final setting is still below what is required based on the speed survey from early 2015. It is unlikely that the second survey was done in free flow conditions and therefore should not be used as a basis for setting the yellow interval. It should also be noted that when both the through and left turn lane yellow intervals were set at 4.7, the city experienced the lowest level of red light violations at these intersections. This indicates that it is necessary to create a workable standard for setting the yellow interval in dedicated turning lanes.

Based on monthly ticketing data, it appears that the city also increased the yellow interval at two to three other intersections with red light cameras. However, since we were unable to confirm the dates and magnitude of these changes, an analysis of these intersections was not completed.

Part 2 – Minimum Yellow Interval for Dedicated Turning Lanes

The results from our analysis of the significant decreases in red light running violations in response to an increase in the yellow interval as mandated by the new signal timing protocols implemented in 2015, suggests that similar roadway safety improvements can be achieved by creating a proper standard for a minimum yellow interval in dedicated turning lanes.

Our previous analysis of increases in the yellow interval in the left turn lanes in Santa Clarita, CA is instructive as to what can be achieved by setting a more realistic yellow interval in dedicated turning lanes.

Analysis of Violation Data in Left Turn Lanes at RLC Intersections in Santa Clarita After Yellow Interval Changes

Santa Clarita employed red light cameras from July 2004 through March 2015. Yellow intervals in the through lanes were set at 5.0 sec. At most camera enforced intersections, there were 2-3 long left turn lanes measuring over 300 feet in length. Prior to signal changes, the yellow interval for the protected left turn movement was set at 3.5 seconds at all RLC approaches in the city. As a result, the vast majority of violations at red light camera enforced intersections were in the left lanes with very few violations occurring in the through lanes.

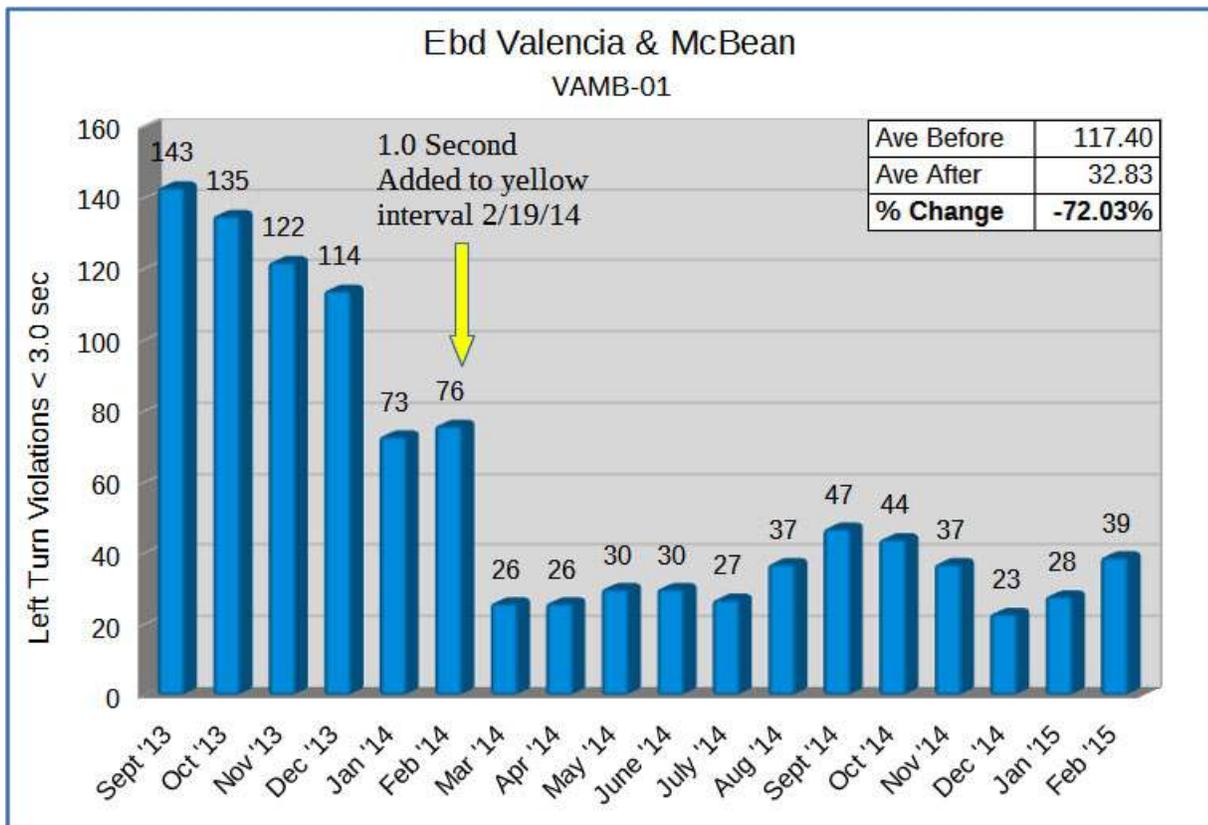
In 2014, city engineers chose to test the effects of increasing the yellow intervals in the left lanes at most camera enforced intersections. Yellow intervals for the left turn movement were increased at seven of the ten approaches. The yellow interval was increased by 1.0 second at both the eastbound and westbound approaches to the intersection of Valencia Blvd and McBean Parkway (VAMB-01 and VAMB-03). The yellow interval was increased by 0.5 second at five additional approaches. The dates of the signal timing changes varied by intersection. Yellow intervals in the left lanes remained at 3.5 seconds at three RLC intersection approaches.

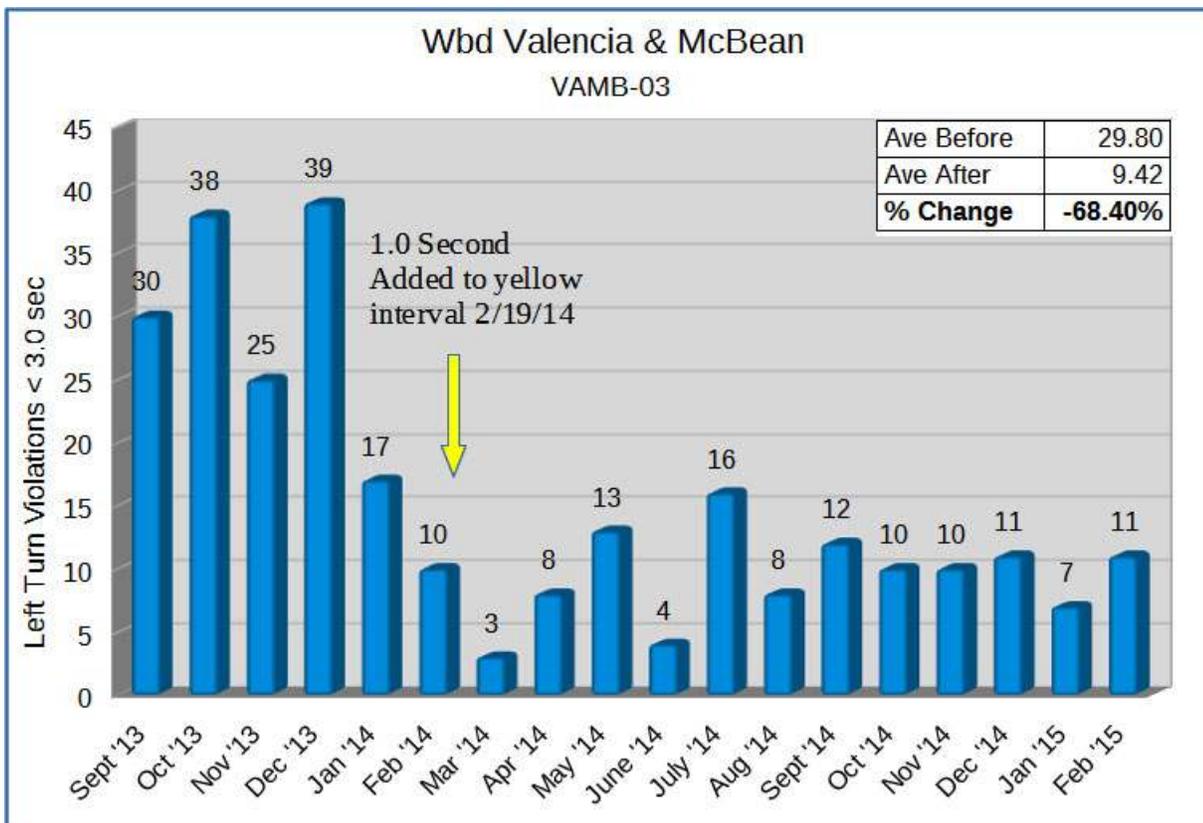
The table below shows the before and after violation numbers and calculated percent change in the average number of monthly violations occurring after the yellow intervals were increased. Yellow highlights indicate the months when the yellow interval was increased.

Santa Clarita RLC Violations Left Lanes < 3.0 sec										
Change Date	02/19/14	02/19/14	02/24/14	08/08/14	08/08/14	07/11/14	07/11/14			
Location	VAMB-01	VAMB-03	NRMB-01	WCSC-01	WCSC-03	BCNR-01	NRBC-01*	BCSC-01	MMMB-01	OVLY-01
Sept '13	143	30	55							
Oct '13	135	38	55							
Nov '13	122	25	57							
Dec '13	114	39	64							
Jan '14	73	17	41							
Feb '14	76	10	22							
Mar '14	26	3	17							
Apr '14	26	8	16							
May '14	30	13	23	72	23	103	93	92	73	16
June '14	30	4	13	75	16	90	89	85	100	17
July '14	27	16	15	85	25	53	59	86	67	16
Aug '14	37	8	14	61	8	26	31	105	91	13
Sept '14	47	12	22	61	13	31	24	114	72	24
Oct '14	44	10	13	54	15	34	30	120	82	25
Nov '14	37	10	13	33	8	31	33	91	60	15
Dec '14	23	11	48	49	17	43	41	78	79	24
Jan '15	28	7	25	37	6	31	40	79	68	14
Feb '15	39	11	16	42	7	41	37	78	74	17
Ave Before	117.40	29.80	54.40	77.33	21.33	96.50	91.00	92.80	76.60	18.10
Ave After	32.83	9.42	19.58	46.00	11.00	33.86	33.71			
% Change	-72.03%	-68.40%	-64.00%	-40.52%	-48.44%	-64.91%	-62.95%			

As expected, all intersections where the yellow interval was increased saw significant reductions in red light running violations with the greatest reductions occurring at the two approaches where the yellow was increased by a full 1.0 second. These intersection approaches experienced an approximately 70% decrease in violations. Where the yellow interval was increased by 0.5 sec., violations decreased in the range of 40% to 65%. No overall reduction in red light running occurred at the intersections where the yellow interval remained at 3.5 seconds.

The following charts show the violation changes over time at the two intersection approaches at Valencia Blvd. and McBean Pkwy where the yellow interval was increased by 1.0 sec.. Although violations fluctuate month to month, overall, violations did not rebound to previous levels.





One caveat is important to note with regards to increasing the yellow interval in turning lanes. The City of Santa Clarita initially had a cycle length of 120 seconds. When the new protocols for additional pedestrian crossing times were mandated, the city was forced to add time to the pedestrian crossing phase and, as a result, to the green time for through traffic. Engineers took the extra time needed from their left turn green intervals. This caused red light running in their left turn lanes to skyrocket, most likely because they were no longer clearing the queue during each cycle and cars that had just gotten up to speed were immediately faced with a yellow arrow. To correct this, engineers increased the cycle length to 132 seconds and put the extra time back into their left turn green interval. Red light running plummeted from the elevated level. Numerous factors go into how much red light running occurs at a particular location and providing sufficient green time to clear the queue should not be overlooked. Therefore, practitioners should be cautioned against reducing green time in turning lanes to accommodate any added yellow time. Instead, the cycle length should be increased.

An Extended Solution to the Yellow Change Interval Duration

The following theory postulating an extended solution to the problem of the yellow change interval duration was developed by Swedish electronics engineer, Mats Järnlström with assistance by Jay Beeber. The new theory was presented at the 2016 ITE International convention. A brief explanation follows. Additional details can be provided upon request.

Background

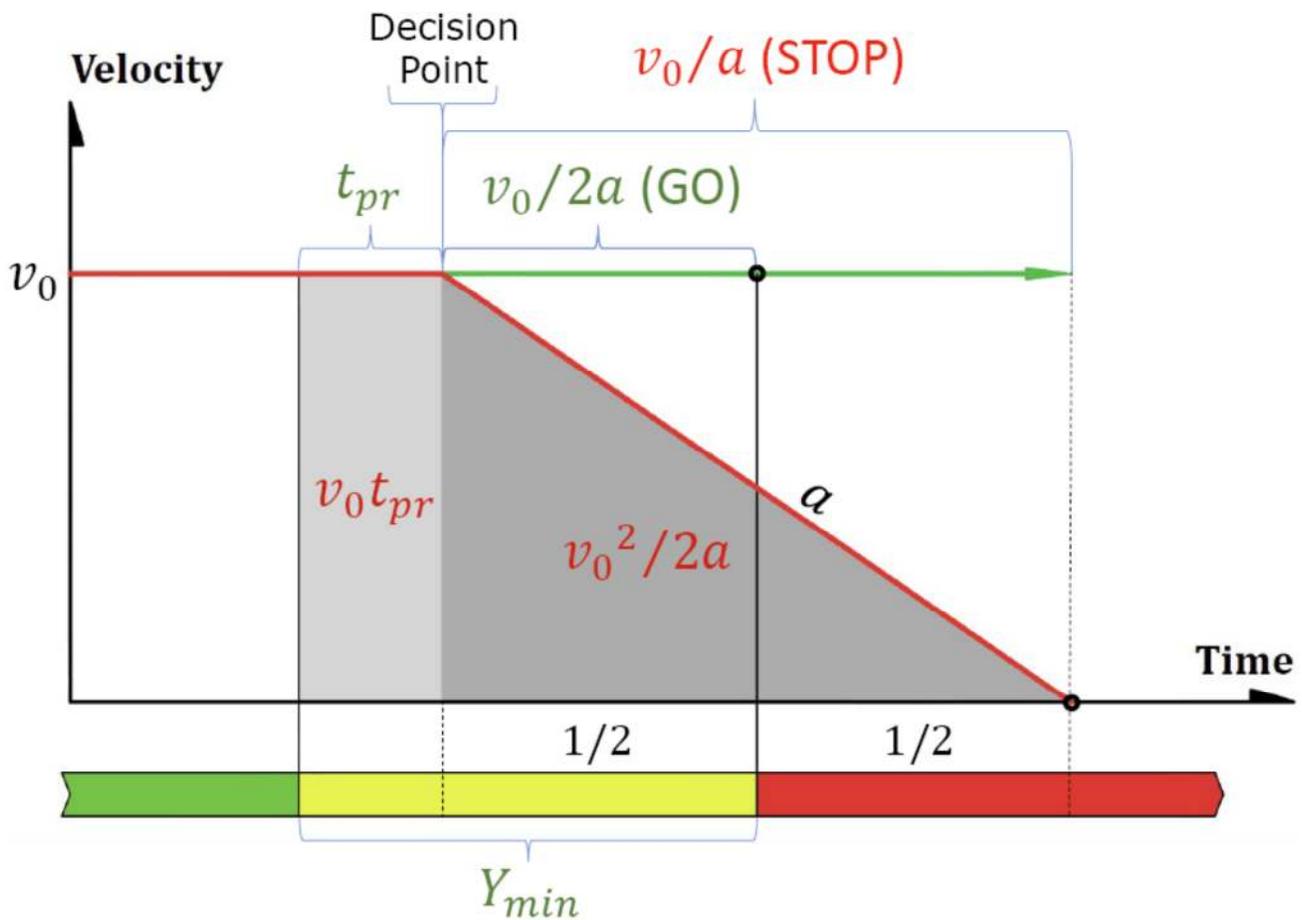
In their 1959 paper, “The Problem of the Amber Signal Light in Traffic Flow”, Gazis, Herman, and Maradudin (GHM), researchers at the GM Research Labs, evaluated the question of whether “when confronted with an improperly timed amber light phase a motorist may find himself, at the moment the amber phase commences, in the predicament of being too close to the intersection to stop safely or comfortably and yet too far from it to pass completely through the intersection before the red signal commences”. That situation is now generally referred to as a motorist “being caught in a type 1 dilemma zone”. The study resulted in a formula (equation 9 in the paper) which traffic engineers

recognize today as the original “ITE Yellow Change Interval Formula” (aka the original ITE Kinematic Formula).

The ITE formula is actually an algebraic combination of two equations of motion, the stopping distance divided by the velocity across that distance, which yields the time to cross the stopping distance. For the driver approaching an intersection and continuing at a constant speed, this is the minimum yellow interval necessary to eliminate the dilemma zone.

GHM Solved a STOP/GO Problem at Constant Velocity

The figure below graphically depicts the motion of a vehicle when the driver makes the decision to stop or go in response to the onset of the yellow indication.



For the driver who “goes” at a constant speed, the time to the intersection entry point is given by the equation:

$$t_{pr} + v_0/2a$$

For the driver who stops, the time to stop is given by:

$$t_{pr} + v_0/a$$

Note that once the driver has made the decision to stop or go (the perception-reaction time), the time to stop is twice the time to go (or alternatively, the time to go is half the time to stop).

But what if you slow down and don't stop? How long does it take to traverse the critical distance?

Logically, the time to slow down and keep going must be somewhere between the time to stop and the time to go at constant speed:

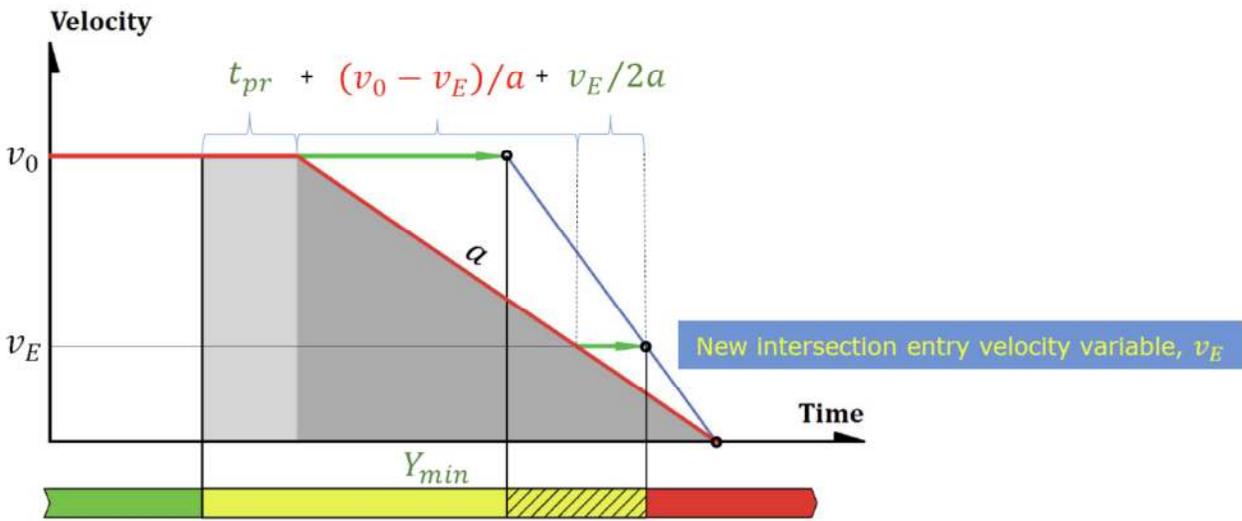
$$t_{pr} + v_0/2a < ? < v_0/a$$

A New Solution That Allows Deceleration

For the driver who must slow down prior to entering the intersection, such as in a turning lane, their time to complete the maneuver can be broken down into three parts:

1. The perception-reaction time
2. The time to slow down to the entry speed
3. The time to continue at the entry speed into the intersection

The figure below graphically depicts the motion of such a vehicle:



To calculate the time to cross the critical distance, add the perception-reaction time to the time to slow down to the entry speed, plus the time to continue at that speed into the intersection.

$$t_{pr} + (v_0 - v_E)/a + v_E/2a$$

We can now simplify the above equation using basic algebra:

$$\begin{aligned}
 \tau_{min} &= \overbrace{t_{pr}}^{\text{React}} + \overbrace{\frac{(v_0 - v_E)}{a}}^{\text{Decelerate}} + \overbrace{\frac{v_E}{2a}}^{\text{GO}} \\
 \tau_{min} &= t_{pr} + \frac{2(v_0 - v_E)}{2a} + \frac{v_E}{2a} \\
 \tau_{min} &= t_{pr} + \frac{2v_0 - 2v_E + v_E}{2a} \\
 \tau_{min} &= t_{pr} + \frac{2v_0 - v_E}{2a} \\
 \tau_{min} &= t_{pr} + \frac{2v_0}{2a} - \frac{v_E}{2a} \\
 \tau_{min} &= t_{pr} + \frac{v_0}{a} - \frac{v_E}{2a}
 \end{aligned}$$

We can check to ensure our theory is correct by entering in the values of the two boundary conditions, stop and go. Where the driver continues at constant speed, such as in a through lane, the entry velocity equals the approach speed $v_E = v_0$ and we arrive at the ITE equation for the minimum yellow time for vehicles that “go”.

$$t_{pr} + v_0/2a$$

Where the driver comes to a complete stop, the vehicle entry speed is essentially zero, $v_E = 0$ which yields the equation for total stopping time.

$$t_{pr} + v_0/a$$

A Real World Example

Rosecrans Ave at Hindry Ave., Hawthorne, CA



Two dedicated left turn lanes over 250 ft. Speed limit = 40 mph. Yellow interval = 3.0 sec. Approximately 9000 citations issued yearly at this intersection.

The time to cross the critical distance (minimum yellow interval) for a vehicle approaching at 40 mph and continuing at constant speed into the intersection would be 3.9 sec.

The total time for a vehicle to come to a complete stop from 40 mph is 6.87 sec.

The time to cross the critical distance (minimum yellow interval) for a vehicle approaching at 40 mph and slowing down to enter the intersection at 20 mph must be between 3.9 sec. and 6.87 sec.

INPUT VALUES (Level Grade):

Approach Speed, $v_0 = 40$ mph (58.7 ft/s)

Entry Speed, $v_E = 20$ mph (29.3 ft/s)

ITE Deceleration Rate, $a = 10.0$ ft/s²

ITE Perception-Reaction Time, $t_{pr} = 1.0$ s

New Equation:

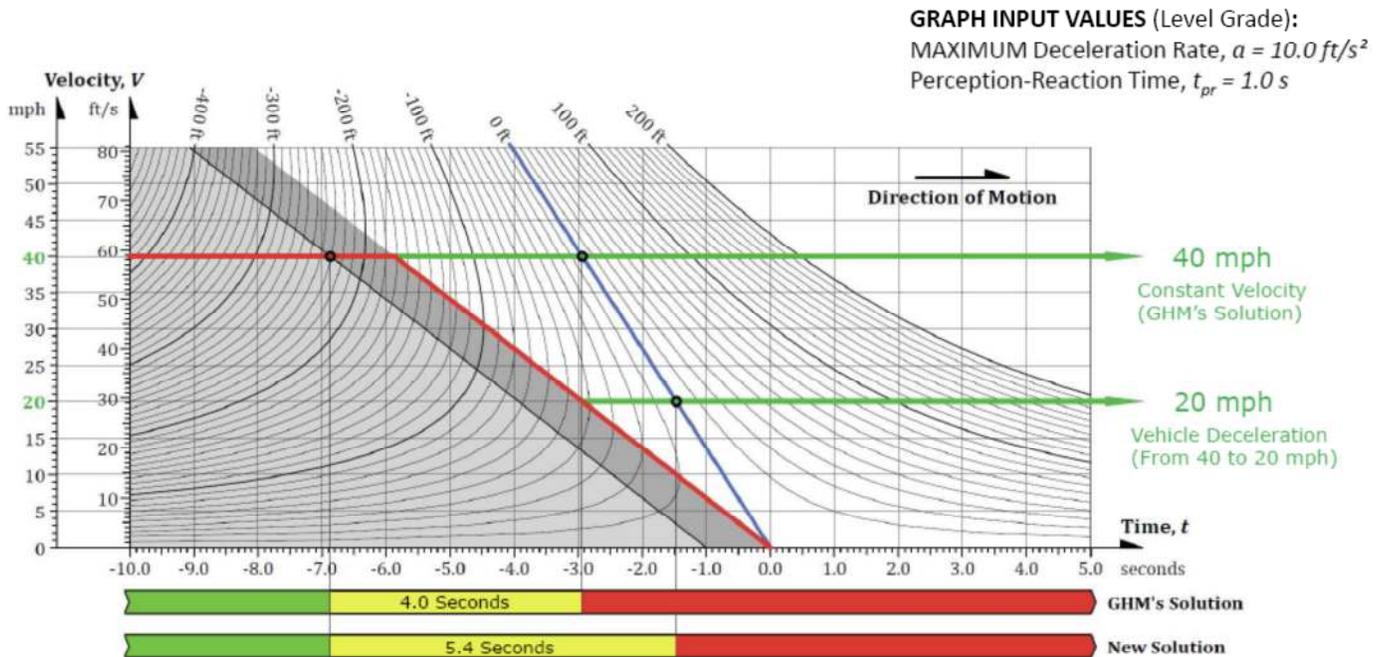
$$\tau_{min} = t_{pr} + \frac{v_0}{a} - \frac{v_E}{2a}$$

New Equation with Values:

$$\tau_{min} = 1.0 \text{ s} + \frac{58.7 \text{ ft/s}}{10 \text{ ft/s}^2} - \frac{29.3 \text{ ft/s}}{2 \cdot 10 \text{ ft/s}^2} = 5.4 \text{ s}$$

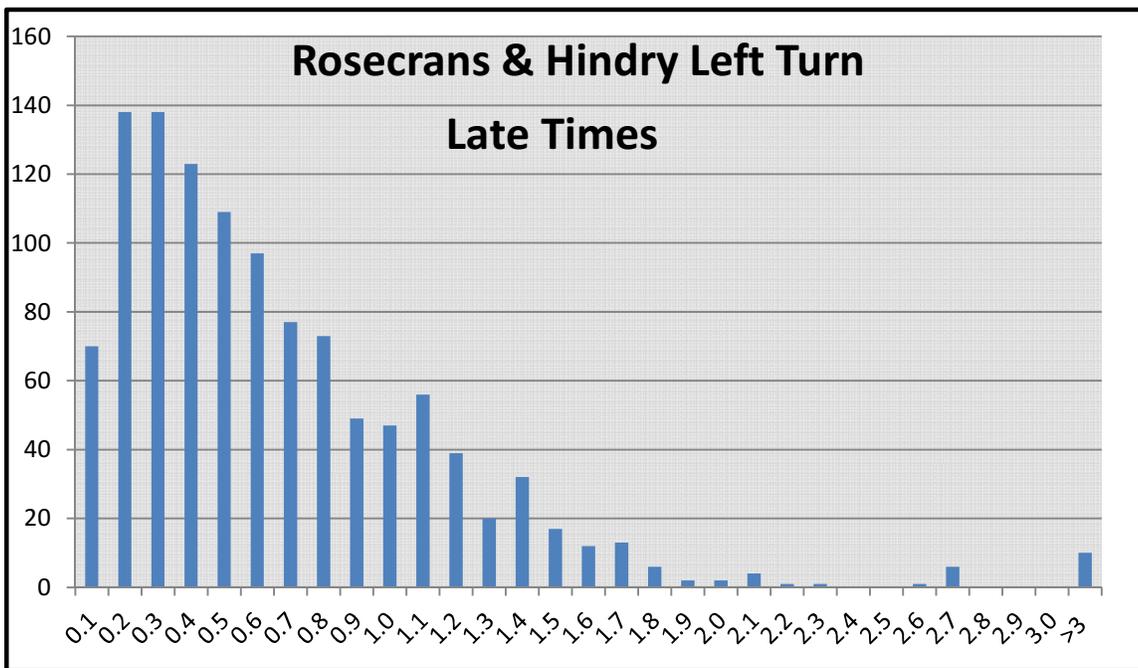
The time to cross the critical distance (minimum yellow interval) for a vehicle approaching at 40 mph and slowing down to enter the intersection at 20 mph is 5.4 sec.

The figure below shows this vehicle motion as a graph.



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Assuming the variables above, the minimum yellow interval would be 5.4 sec. The current yellow interval is 3.0 sec., 2.4 seconds too short. Drivers routinely encounter a dilemma zone. The pattern of violations at this intersection shows the problem.



Note that almost all violations at this intersection occur in the 2.4 second range, exactly the time difference between the current yellow interval of 3.0 sec, and the calculated minimum yellow interval of 5.4 sec. arrived at using the extended solution.